# Impact of Waste Plastics and Glass on Soil Biotic Activity

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## INTRODUCTION

### Problem Statement

#### A UBIQUITOUS PROBLEM

Waste plastic and glass containers are found discarded in all landscapes; they are generally characterized by unsatisfactory biodegradation once disposed of in these aquatic marine or terrestrial environments. Burial of solid wastes (including plastics and glass) in landfill sites has become commonplace in most parts of the world. Many negative conditions from dumping in landfills may result such as ground water contamination, concentration of heterogeneous mixtures of toxic compounds, public repulsion of unsightly landscapes, unpredictable settling of dump site land masses and lack of productivity of large tracts of land.

#### GENERAL HYPOTHESES

As an alternative to massive landfill or waste tip operations, finely divided or milled solid waste items may be mixed with soil thus providing both extended use of waste deposit sites and more efficient spatial land usage. Being relatively inert and recalcitrant, waste plastic and glass, if reduced in particle size, may have similar or the same effects on decomposer soil biota as natural inert sand. Also, if limited biological transformation of plastics or glass can eventually occur via physical abrasion and/or chemical decomposition, particle size reduction and the associated increased surface area should accelerate the processes.

The objective of this research was therefore to determine the impact of selected finely divided waste materials on decomposer soil biota particularly the responses of the soil microbial community and the earthworm Lumbricus terrestris L. within soil microcosms.

#### RESEARCH RELEVANCE

Co-composting is a process of solid waste management and recycling that has been adopted successfully in Holland, Sweden, Austria and Canada. It has been found to be an effective alternative in solving solid waste problems of major municipalities. Following the European lead, proponents are trying to establish the process in the United





States. This "biotechnological" process emphasizes 1) "particle size reduction" of solid waste materials, and 2) mixing of municipal sewage sludge (as a nitrogen source) to "co-compost" with the finely divided solid waste particles. Data from the European plants show that the initial sludge and solid waste bulk is reduced from 50% to 90% over typical unprocessed landfill deposits (Epstein, pers. comm. 1983). Depending upon the concentration of toxic waste this processed material is disposed of in many ways. Co-compost which is chemically harmless is mixed with vineyard soils in Heidelberg. Many hazardous organic compounds are found to be very efficiently and effectively biodegraded within the co-compost mixture. Even though most of the compost product derived from this technology is put back on the land little is known about its influence on the vitally important biotic component of the soil. This research provides some initial information.

## LITERATURE REVIEW

#### SOLID WASTE PRODUCTION

Approximately 15.5% (by wt ) of the total solid waste generated in United States during 1980 was plastics and glass (Archer and Huls 1981), a proportion relatively high taking into account the impact of their great longevity in the environment. In Norway an average of 74000 T/yr of plastics and glass were disposed as household wastes in 1981. This amounts to about 10.2% (5.1% plastic and 5.1% glass by wt) of the total annual solid waste in that country (Heie and Minaas 1982).

#### COMPOSITION, DECOMPOSITION AND ENVIRONMENTAL PERSISTENCE

"Artificial sand." Glass is made from soda ash, limestone and sand as the basic raw materials. It comprised 10.3% (by wt) of the total solid waste in USA in 1980 (Archer and Huls 1981). Ninety per cent of glass waste was in the form of container glass in municipal waste (Duckett 1978). Its chemical inertness and its impermeability to liquids and gases are properties responsible for its environmental persistence.

Synthetic polymers relevant to this research. Plastics represented 5.3% (by wt) of the total solid waste in the U.S. in 1980, whereas 80% of the plastics produced in 1977 were thermoplastics, plastics with the property to soften upon heating, which are the main source of plastics found in municipal wastes in the form of packaging materials (Archer and Huls 1981). The commonest plastic waste of this type is polyethylene comprising 66% (by wt) of the packaging plastics in the United Kingdom (Brown et al. 1974). A smaller portion of municipal packaging thermoplastic wastes is composed of polystyrene, a large proportion of which is in the form of molded polystyrene foam (Crosby and Kochis 1972).

Synthetic polymers-microbial degradation. The recalcitrant nature or persistence to biodegradability of synthetic polymers has initiated and produced a great amount of biodegradation studies in the last decade. The resistance of such polymers to microbial attack is caused by the lack of genetic information in the microbes to produce enzymes capable of degradation, by the lack of readily available sites to be enzymatically cleaved, by the large size of polymer molecules being impermeable to cell membranes for intracellular breakdown, by the need of microbial co-oxidation or co-metabolism and by the very low concen-

trations of these compounds in aqueous solutions (Alexander 1975, Faber 1979).

Polyethylene: The biodegradability rates of polyethylene by microorganisms, the principal true decomposers, was extremely slow in laboratory and field experiments. Albertsson (1978) recorded 0.5% biodegradation of high density polyethylene (HDPE) during a two year exposure period in the soil and in a culture of wood rot fungi and 0.36% in a later experiment (Albertsson and Banhidi 1980) where the short-chain oligomeric fraction of the main crystalline material was primarily utilized. The degradation curve of HDPE was similar to that of low density polyethylene (LDPE), a more inert material (Albertsson 1980). Nykvist (1974) observed some $^{14}CO_2$ liberation after exposing LDPE to UV radiation. The tensile strength of LDPE was greatly lost after only several weeks burial in warm composting garbage (Griffin 1976), but loss of tensile strength is not necessarily indicative of biodegradation.

Polystyrene: The recalcitrant nature of polystyrene to biological decay was indicated by Kaplan et al. (1979) when this material was incubated in a number of enriched media such as manure, sludge and garbage as well as silt loam, garden and farm soil. The early $^{14}CO_2$ release was attributed to oligomeric residues or trace impurities. Fungi showed limited ability to degrade polystyrene with a maximum value of 0.29% biodegradation after 35 days. During a four-month soil burial 1.5-3.0% of the total $^{14}CO_2$ evolved in a study by Sielicki et al. (1978), the highest rates of decomposition recorded in landfill soil. Guillet et al. (1974) found 0.3-0.8% $^{14}CO_2$ production in polystyrene mixed with 5% photo-oxidised vinyl ketone.

Synthetic polymers and invertebrate decomposers. The effect of marine and terrestrial invertebrates on plastics has been reviewed by Griffin and Turner (1980). Limnoria (Gribble), Teredinidae (Shipworms) and Pholadinae (Piddocks) were likely organisms for the destruction of underwater plastic cable sheathing. The terrestrial isopods Porcellio scaber Latr. and Oniscus asellus L. ignored normal polyethylene but attacked starch extended polyethylene plastic films, when both normal and modified materials were offered simultaneously. Positive proof of ingestion of plastic material with starch inclusion came from examination of the fecal pellets. Kuhne (1969) observed adoption of plastic foams, especially polystyrene, as nesting sites by Sphecidae and Tenebrionidae species whereas all plastic foams were severely damaged by termites (Ong and Stanton 1977). Thus, under favourable conditions certain invertebrates can significantly degrade or fragment some kinds of plastic. But Kaplan et al. (1979) were unable to find any soil invertebrates (or microbes ingested by them within their fecal pellets) which would biodegrade tiny pieces (0.045 $\mu$Ci) of polystyrene, poly (methyl methacrylate) and phenol formaldehyde in a laboratory experiment of 14 days duration. The soil invertebrates tested were representative of the groups Isopoda, Diplopoda, Gastropoda and Oligochaeta.

Synthetic polymers:potential effect on earthworms. Plastic solid particle ingestion has been reported to harm earthworms. Rather accidentally Wright (1972) discovered inhibitory feeding effects on the earthworm, L. terrestris, after polyester foam strips were found lodged in the gizzard. Detrimental effects caused by particle ingestion in other animals was also reported by Carpenter et al. (1972) during a study of fish living in industrially polluted coastal waters of southern New England. Intestinal blockage in small fish was hypothesized after consumption of polystyrene spherules by 8 out of 14 fish species examined.

The incorporation of hydrophobic and long-lived material particles in a soil environment causes increased soil moisture loss and, therefore,



lower moisture content. Soil moisture influences the activity and weight of earthworms. Drought of the topsoil causes withdrawal of adult L. terrestis to move deep in their burrows, whereas extreme drought stimulates quiescence (Pieargе 1981). Hydrothermal conditions, soil temperature and moisture, determine the amount of body water, and thus weight, of earthworms (Adolph 1927, Kudrjaseva 1982). Greater than 20% body weight loss results in amplitude loss of spontaneous contractions of body wall muscles of L. terrestris (Wolf 1940), whereas mobility was greatly reduced at 30% weight loss of the same species (Pieargе 1981) under adverse moisture and heat conditions.

Synthetic polymers:physical decay. Particle size reduction of packaging plastic waste can also take place abiotically by weathering degradation or oxidation initiated and accelerated by the high energy of UV light (Baum 1974). Carbonyl and peroxide impurities in the polymer will induce photodegradation which can be accelerated by inclusion of additives (i.e., benzophenone and quinones) or by copolymerization, i.e., with phenylvinyl ketone (Sheldric and Vogl 1976). Ignoring the problems associated with the effectiveness of weathering or photodegradation in the environment, the end product of particle size reduction is comparable to the mechanical fragmentation of plastic containers applied in this study.

Assuming it can be achieved by mechanical, macro-biological or photochemical (photodegradable) means in a landfill situation, particle size reduction is one way of making plastic solid wastes potentially more biodegradable in the environment (Faber 1979).

## METHODS AND MATERIALS

### STUDY SITE AND CONDITIONS

The study was conducted at the Soil Invertebrate Ecology Laboratory at the Lafayette Experimental Station of the SUNY College of Environmental Science and Forestry in Syracuse, New York, USA from July 26 to September 17, 1982, an experimental period of approximately 7.5 weeks.

A total of 136 pot microcosms were investigated. All were housed in an open glasshouse shaded to 95% to simulate below forest canopy conditions. Experimental soils were therefore all subjected to the same ambient temperature and ventilation conditions.

### PREPARATION OF EXPERIMENTAL SUBSTRATES FOR MICROCOSMS

The following solid waste materials were finely ground and mixed in 5, 30, 60 and 90% (by vol.) concentrations with sandy loam clay subsoil (13% sand, 53% silt, 33% clay; 2.65% OM) of the Cazenovia series (Alfisol: Glossoboric hapludalf USDA 1972 ):

SAND (SA) - aquarium grain No. 3;
GLASS (GL) - beer bottles finely ground in rotary drum;
POLYSTYRENE FOAM (ST) - packing material, ground in blender;
POLYETHYLENE (PL) - milk, detergent and bleach bottles, finely divided in a Sprout-Waldron double disc refiner.

Unless otherwise indicated reference to synthetic polymer plastics will include both polyethylene and polystyrene. Particle size distribution of each of the experimental solid waste items is given in Table 1.

Milk bottles constituted 35% (by wt) of the total bottles used and were composed of low density polyethylene as determined by infrared absorption photo-spectroscopy (Perkin-Elmer 1310 Infrared Spectrophotometer)

and confirmed by Edmunds (1977-1978) and Crosby and Kochis (1972). The same authors report the majority of bleach and detergent bottles presently on the market are composed of polyethylene, thus leading to the assumption that the principal constituent of the bottles used in this experiment was polyethylene.

After manually mixing the dried material particles with dry subsoil, these soil-material mixtures were transferred to 3.8 L (1 gal), open-mouthed glass containers, each containing 1.9 L (0.5 gal) of the dried mixtures.

Concentration mixtures were based upon volume due to the very large differences in density of the experimental materials.

Each material concentration in the containers will be referred to as "treatment", thus having 17 different treatments altogether including the control (100% subsoil). Each treatment consisted of eight replicates which were randomly distributed in eight rows, each row containing 17 different treatments or one replicate of each. Furthermore, four replicates of each treatment were used as earthworm or "treated microcosms" whereas the remaining four did not contain any earthworms (untreated microcosms). The design was such that each of two adjacent rows contained one replicate of the same treatment, one row with a treated and one with an untreated replicate in a random manner.

WATER CONTENT OF MICROCOSMS

The initial moisture content applied in the microcosms was based on the water holding capacity (WHC) of each treatment with the purpose of 1) minimizing rapid water evaporation in high solid waste concentration treatments (moisture content ≥65% WHC), and 2) insuring avoidance of anaerobiosis in the control and low solid waste concentration treatments (moisture content of 50% WHC).

Core samples were taken at the termination of the experiment from the untreated microcosms to determine final microcosm moisture content and per cent microcosm moisture loss was calculated by the formula:

$$\% \text{ moisture loss} = \frac{(\% \text{ initial moist. content} - \% \text{ final moist. content}) \times 100}{(\% \text{ initial moisture content})}$$

EARTHWORM AND LEAF COMPONENTS OF MICROCOSMS

After the establishment of specific moisture conditions, 4 ± .05g of dried maple leaves (Acer saccarum Marsh.), with petioles removed, were placed in all replicates as an energy source for microcosm biota. Two healthy, adult earthworms (Lumbricus terrestris L.) were weighed and introduced to half (4) of the replicates of each treatment, as specified previously. Live earthworms and redried leaves were reweighed immediately after the termination of the experiment for every replicate.

INITIATION OF EXPERIMENT, RESPIRATION AND TEMPERATURE MEASUREMENTS

Immediately after earthworm introduction, all microcosms were kept covered with jute-burlap sheet to prevent entrance of sunlight and to reduce microcosm moisture loss. Burlap sheets were sprayed regularly (4 times/wk) to maintain moisture and also cause gradual leaching of the maple leaves inside the microcosms. Leached apple leaves were consumed seven times faster than unleached leaves in a similar laboratory experiment (Wright, 1972).

Biotic respiration in the microcosms was measured by means of $CO_2$ evolution. A solution of 0.6 N NaOH (20 ml) was placed as a $CO_2$ collector



in each microcosm. The microcosm was subsequently sealed by means of a glass cover and silicate gel for 17 hr. The hydroxide solution was titrated with 0.3 N HCl to a phenolpththalein indicator end point. The amount of $CO_2$ evolved was calculated by the equation: mg $CO_2$ evolved = (titer control-titer sample) x normality HCl/2 x 44 mg $CO_2$/mmole. $CO_2$ evolution was sampled once a week for each replicate.

## RESULTS AND DISCUSSION

### Specific Biotic Responses

MICROCOSM MICROBIAL RESPIRATION

Microbial respiration, as measured from untreated pots (those without earthworms), after reaching an initial maximum, gradually declined reaching final equilibria by week 6 in all but 90% treatments (equilibrium by week 3). The drying-wetting effect (Birch 1960) was responsible for the initial increased flux in microbial activity, however whether any other factors were involved it was not clear. Similarly, the reasons for the difference between the 90% and all the rest of the treatments in equilibrium time was not apparent.

It seems that moisture was not the only variable accounting for differences among materials ($r = .78$ for final moisture content); differences in particle size as well as in physico-chemical properties between materials may have played a part.

The pattern of microbial respiration for different concentrations of the same materials is shown in Figure 1. In most all cases, microbial respiration generally was negatively correlated to material concentration in the soil, a pattern related to the amount of soil particles in the top strata, since all materials used were more or less recalcitrant. The exception was the 30% sand treatment which had a higher, but not significantly different, mean respiration than 5% sand.

Sand microcosms had the highest microbial respiration ($\bar{x}$ =42.96 mg $CO_2$/pot vol /17 hr) after control ($\bar{x}$ = 55.73), polystyrene and glass microcosms had intermediate values, 38.69 and 38.31 mg $CO_2$/pot vol /17 hr respectively, whereas microcosms with polyethylene plastic had a mean of 36.18 mg, a reflection of the more recalcitrant nature of the plastic particles.

RESPIRATION OF L. TERRESTRIS

Relevant definitions. "Earthworm respiration" was calculated as the difference between treated or earthworm-containing microcosm respiration and its respective untreated or microbial microcosm respiration for each treatment. Actually, as defined here, earthworm respiration probably represents the respiration of L. terrestris plus that of its microbial symbionts (Dindal, pers. comm. 1982). Since there is no way known at present to delineate these two interactive components it will be referred to as "earthworm respiration" for comparative purposes.

Data are presented in mg $CO_2$/pot vol/ test period (17 hr), which will be referred to as "microcosm earthworm respiration", as an effort to determine earthworm activity in a volumetric soil microhabitat (in situ) versus the more sterile in vitro respirometric laboratory condition as per Johnson (1942); our approach is more practical under field conditions.

However, in order to show comparisons to previous standardized laboratory studies and to compare respiration with other variables of living

worms (i.e., body weight loss), data will also be presented in mg $CO_2$/g fresh wt/hr. This is accomplished by selecting data from pots containing worms of known original and final weights, and it will be referred as "individual earthworm respiration." The mean individual earthworm respiration of each treatment is shown in Figure 2; the lower values obtained in most treatments, as compared to those reported by Johnson (1942) and Byzova (1965), were possibly a result of under-estimation of respiration because the respironmetric and manometric techniques, respectively, employed by the above workers were of greater accuracy than the technique employed here. In most treatments, the low readings were also a reflection of depression of activity due to greater than 20% body weight loss (Wolf 1940) and solid waste particle ingestion.

Statistical analysis of microcosm earthworm respiration. Repeated measurement split-plot analysis of variance showed the difference between treatment means to be highly significant ($Pr < .004$). Similarly, the difference between weekly means was highly significant ($Pr < .0001$); the constant decline in respiration from the second week to the termination of the experiment was caused by earthworm mortality and possibly by increasingly dry conditions of the top of the soil in the microcosms.

The treatment effects were separated into material effects and per cent concentration effects. General linear model procedures were employed to analyze the differences between respiration means in each of these two components of treatment. The difference between material means ($Pr < .0002$) was more significant than the difference between per cent concentration means ($Pr < .055$) (Figure 3). Thus the effects of materials were more significant than the effects of concentration on earthworm respiration. Student-Newman-Keuls procedure was employed for multiple comparison of the above means.

L. TERRESTRIS BODY WEIGHT LOSS

With only one exception, all experimental, fully-hydrated, earthworms lost weight ($\bar{x}$ = 27.81%)--actually body water as verified by Adolph (1927) and Kudrjaseva (1982)--ranging from 17.46% in 5% glass to 71.31% in 90% plastic after an 8 week incubation period of experimental conditons. Body weight loss was correlated positively to microcosm final water content (Figure 4), a relation confirmed by Kudrjaseva (1982), and to per cent material concentration in the soil ($r = .92$ excluding control, $r = .88$ including control).

Piearge (1981) reported that mobility was greatly reduced at 30% weight loss. This effect was not apparent in my study, except in 90% polystyrene because particle ingestion had an effect on earthworm activity as measured by respiration and leaf consumption.

There were no significant differences between material means but the high mean body weight loss in 90% concentrations was found statistically different ($pr < .10$) from all other concentration means, again emphasizing the impact of very low water content of 90% treatments.

SURVIVAL OF L. TERRESTRIS

Earthworms in 60% concentrations had the highest mean survival (97%) and following in decreasing order of survival were 5% (87.75%), 30% (78.5%) and 90% (68.88%) material concentrations.



EARTHWORM PARTICLE INGESTION

Material particles were found throughout the gut of dissected earthworms in all material treatments but polystyrene. No polystyrene particles were found in any earthworm gastrointestinal tracts.

## Holistic Microcosm Dynamics

COMPARISON BETWEEN MATERIALS (LEAF CONSUMPTION = LCNS)

The relation of microcosm and earthworm variables as well as their degree of influence on earthworm performance with each material are presented in Figures 5-9.

It seems that the most important variable determining LCNS in this study was material particle ingestion by earthworms. Wright (1972) observed that L. terrestris L. would not feed on softened apple leaves for, at least, seven days after swallowing three pieces of polyester foam strips each, while the strips were found to be lodged in the gizzard after dissection. Sand, polyethylene and glass particles were found throughout the alimentary canal of earthworms at all concentrations. Sand particle ingestion did not greatly affect earthworm LCNS since mean individual LCNS (17.76 mg/g/8 weeks) was not far below that of control earthworms (19.89 mg).

On the other hand, polyethylene and glass ingestion had a marked influence on LCNS, being extremely low in both cases (Figures 5-9). The sharp edges of glass particles may have traumatized the worms by both their presence in the gut, which is believed to be the cause of the lowest individual leaf consumption, and by their contact with the body wall externally (mortality of a single worm was observed and caused by external hemorrhage in a 90% microcosm). Although polyethylene particles should not be capable of internal or external damage to the worms, they too may have caused stress expressed in terms of low LCNS and low respiration. On the contrary, the highest LCNS occurred in polystyrene microcosms where worms did not ingest any of those particles. The very high mean for earthworm LCNS on an individual basis in 60% polystyrene (four times greater than that of the control) was significantly different ($Pr < .05$) from all other treatment means. On a microcosm basis the mean LCNS for earthworms (310 mg leaves/pot/8 weeks) in polystyrene was nearly twice as much as that of the control worms, whereas LCNS means in sand, glass and polyethylene were much lower (70, 50 and 30 mg leaves/pot/8 weeks, respectively).

The reason earthworms did not ingest styrofoam particles may be the ease of recognition of such particles by the worms because of the lighter weight and larger size of the particles. Perception of chemical and/or surface characteristics may also have caused a repugnant response.

Encounter and/or ingestion of particles is, also, believed to have caused quiescence or inactivity (low respiration) of worms in the 5% glass and 30% polyethylene microcosms. Low moisture content can cause retreat and torpidity of L. terrestris adults deep in their burrows (Piearge 1981), but final moisture content was high in both treatments.

In general, earthworm microcosm respiration was positively related to LCNS (Figure 10) with a similar pattern occurring when plotting the individual earthworm variables. The low respiration of worms in polystyrene relative to their LCNS is not clear. It is hypothesized that this relatively low respiration was a result of the presence of the light styrofoam particles in the soil so that ease of movement through the medium would lead to less expenditure of energy. Thus, the posi-

tive correlation of LCNS with respiration, with the exception of worms in polystyrene, may indicate an influence of particle ingestion on respiration as it appears to be the case on LCNS.

The depressing effect of high weight loss (>30%) on mobility (Piearge 1981), and thus respiration, was not apparent on earthworms of glass, sand and polyethylene treatments possibly showing that particle ingestion of these materials caused the unpredictable respiration in such treatments. However, such an effect was observed in earthworms exposed to styrofoam where no particle ingestion was evident. More specifically, 90% polystyrene exposed earthworms lost a mean of 34.5% of their weight, while their respiration was lower than in any other polystyrene treatment (Figure 2), being lowest at the final two weeks of the experimental period when they should have exceeded the 30% weight loss mark.

Mean earthworm weight loss was determined by the interaction of a number of factors and their relative importance was different in each material as shown in the flow charts. The low LCNS, the low final moisture content and particle adherence on earthworm body at high polyethylene concentrations brought about the highest body weight loss in polyethylene microcosms. The low weight loss of earthworms in glass microcosms, despite the very low LCNS, was primarily the result of high moisture content; quiescence in the 5% treatment should, also result in low weight loss. The comparatively intermediate weight loss of earthworms in sand was mainly the product of low moisture content while the relatively high mobility should have a contribution to the weight loss. The greatly increased LCNS in polystyrene microcosms, as a result of no particle ingestion, brought about a small body weight loss despite the very low mean final water content. Finally, the small weight loss in the control pots was related to high moisture content.

The negative correlation of survival to earthworm weight loss (r=-.95, Figure 11) of material means indicates the importance of the body weight loss variable in constructing Figures 5-9, since this variable is the result of the simultaneous interaction of moisture content, LCNS and respiration, and, therefore, such a correlation should confirm the relationship between all these variables as shown in the flow charts.

Finally, microcosm earthworm respiration and LCNS can be estimated by taking into account earthworm mortality and individual earthworm respiration and LCNS, respectively. In the case of microcosms with 100% earthworm survival, earthworm microcosm respiration or LCNS is equal to its individual counterpart.

GENERALITIES ABOUT MATERIAL CONCENTRATIONS

Even though microbial respiration was correlated negatively to material concentration in the soil microcosms, no correlation was found in microcosm earthworm respiration relative to waste material concentrations as was shown in Figure 3.

There was a positive relation of per cent material concentration to microcosm moisture loss (Figure 12). The relatively high moisture loss in 90% untreated microcosms should be caused by the larger pore space of these treatments, thus facilitating exposure of greater soil aggregate surface area to air and increasing water evaporation.



## CONCLUDING SUMMARY

Soil moisture content was negatively correlated to per cent concentration of materials in the soil.

Microbial respiration was negatively correlated to solid waste concentration in the soil and microbial activity in sand substrates significantly higher than that in plastic and glass substrates. Polystyrene foam was never consumed by earthworms while the mean earthworm activity in polystyrene media was maximal. All other particles were ingested at all concentrations whereas earthworm activity was depressed in these solid waste environments. Earthworm respiration was positively and highly correlated to log representation of leaf consumption when material means were compared. Earthworm body weight loss was dependent upon soil moisture content and earthworm activity. Body weight loss was highly proportional to earthworm mortality when material means were compared. Earthworms living in 90% solid waste concentrations lose significantly greater weight than in all other concentrations. Polyethylene particles at 60% and 90% had more pronounced effects on body weight loss than any other materials. High glass concentrations in the soil can cause earthworm haemorrhage by physical contact of glass particles with the external body walls. However, in general, the effects of materials were more significant than the effects of per cent concentrations on earthworm respiration.

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Table 1. Particle size of solid waste materials (% by wt)

| | >4 mesh >4.76 mm | 4-9 mesh 4.76-2.00 mm | 9-20 mesh 2.00-0.84 mm | <20 mesh <0.84 mm |
|---|---|---|---|---|
| POLYETHYLENE | 0.76 | 33.35 | 42.72 | 23.11 |
| POLYSTYRENE | 34.19 | 55.98 | 8.12 | 1.71 |
| GLASS | 3.48 | 42.58 | 44.08 | 9.86 |
| SAND | 0.00 | 91.39 | 8.61 | 0.00 |



Figure 1: Microbial respiration of treatments grouped by material.

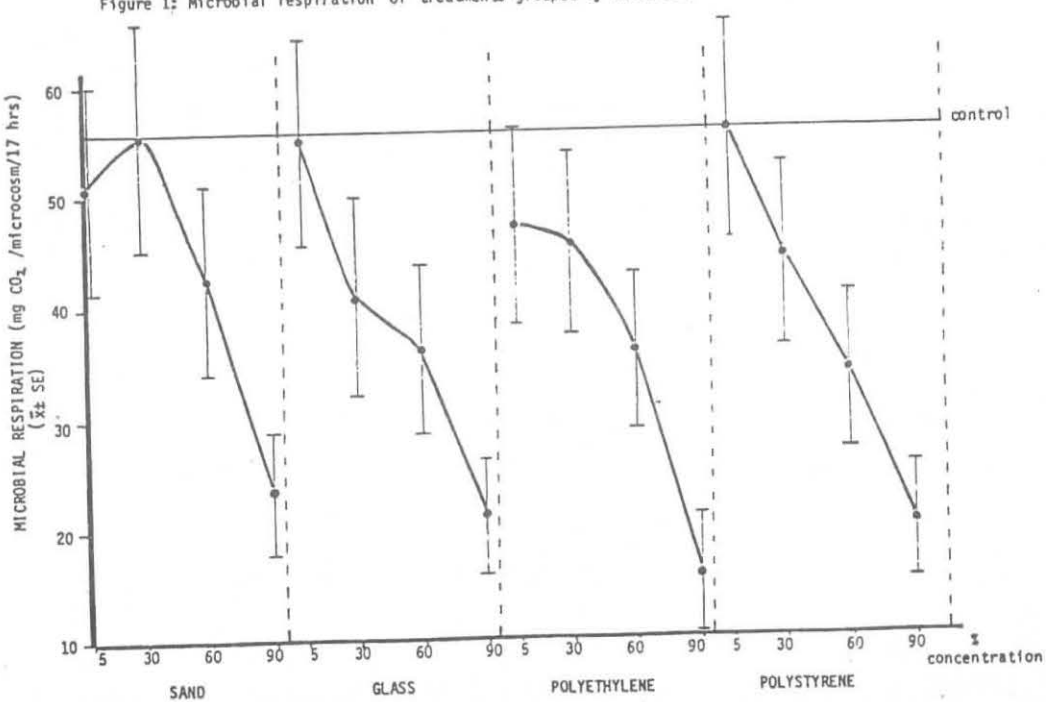


Figure 2: Comparison of earthworm respiration under standard laboratory conditions (Johnson's 1942) vs. respiration in soil microcosms.

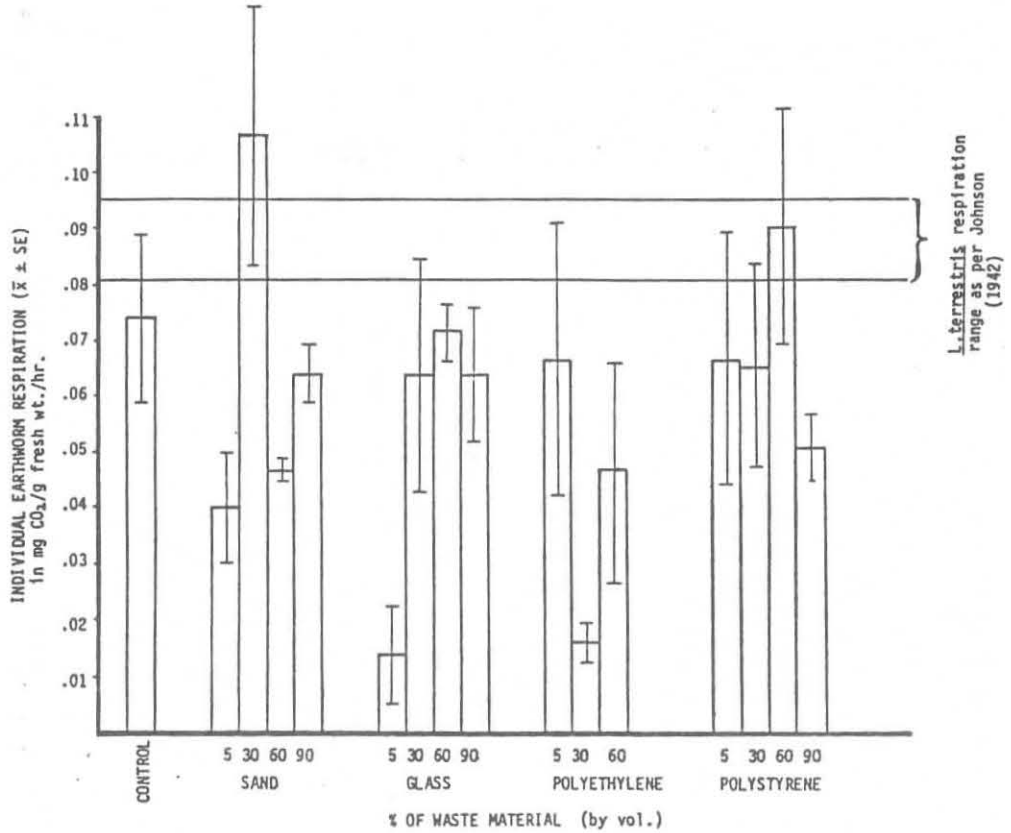





Figure 3: Comparison of earthworm respiration in microcosms containing different material concentrations.

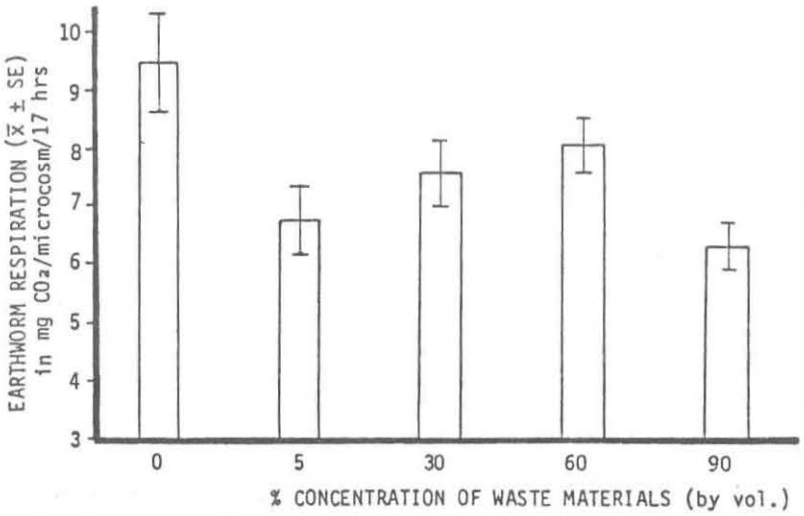





Figure 4: Weight loss of Lumbricus terrestris vs. microcosm moisture content (numbers represent percent concentrations of each material).

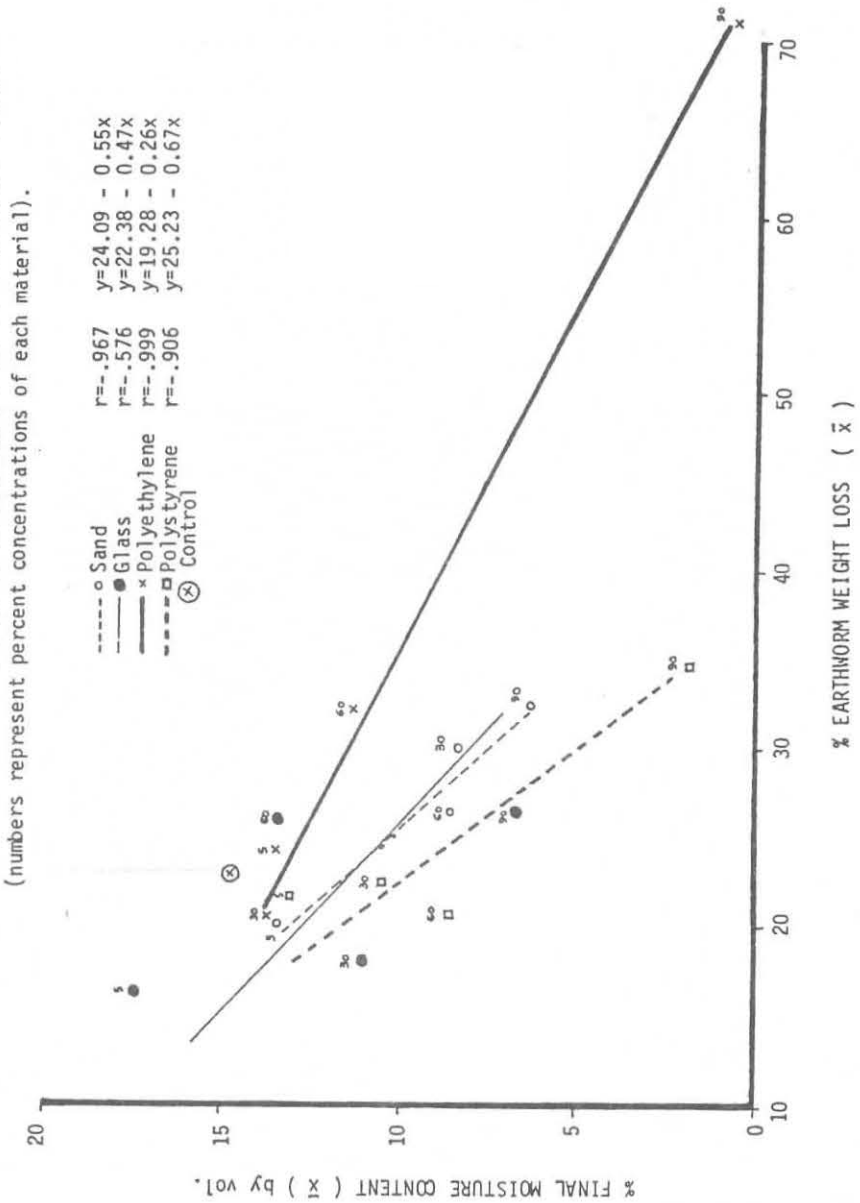
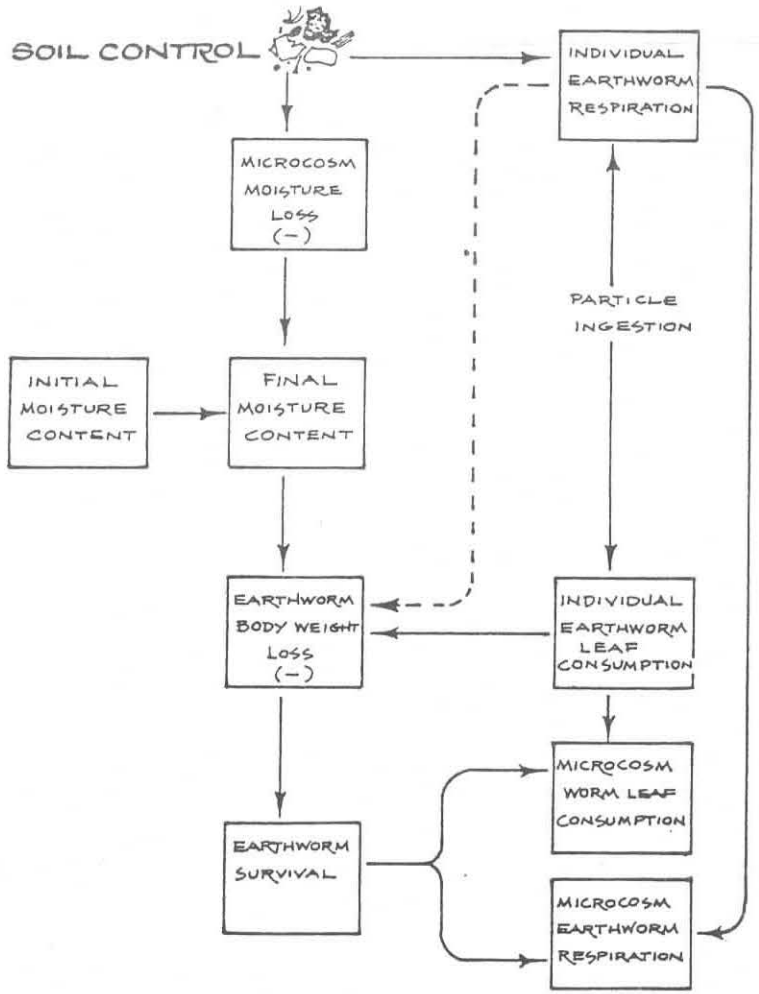


Figure 5

FACTORS AFFECTING EARTHWORM VITALITY
IN CONTROL MICROCOSMS
(EACH RECTANGLE REPRESENTS 100% VALUES) □ = 5%

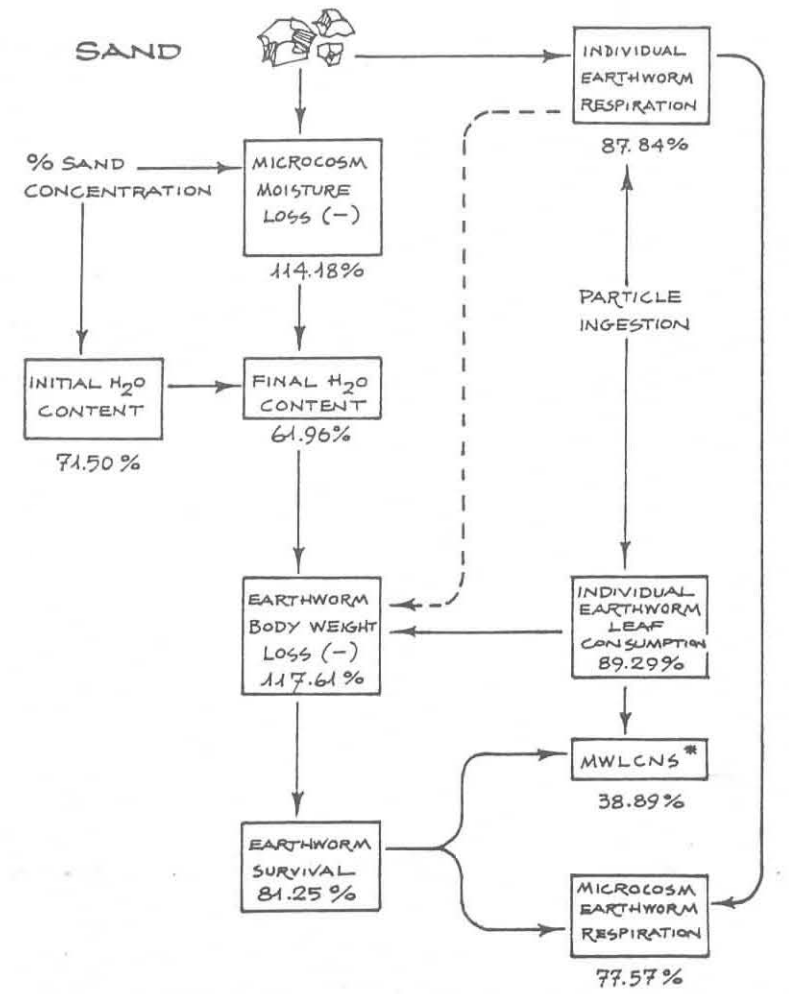



ARROWS DENOTE RELATIONSHIPS



Figure 6

FACTORS AFFECTING EARTHWORM VITALITY
IN SAND – SOIL MICROCOSMS
(RECTANGLE SIZES RELATIVE TO 100% CONTROL VALUES) □ = 5%




ARROWS DENOTE RELATIONSHIPS
* MWLCNS = MICROCOSM EARTHWORM LEAF CONSUMPTION

Figure 7

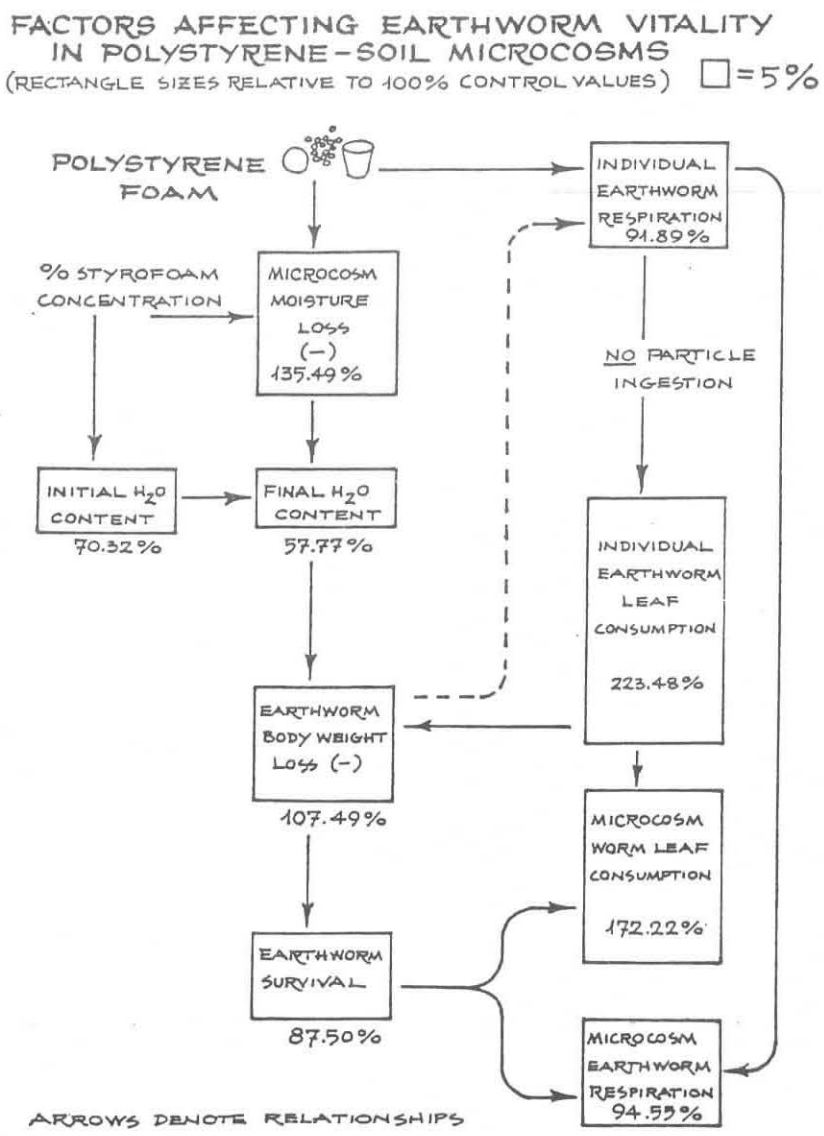

FACTORS AFFECTING EARTHWORM VITALITY
IN POLYSTYRENE-SOIL MICROCOSMS
(RECTANGLE SIZES RELATIVE TO 100% CONTROL VALUES) □=5%
POLYSTYRENE FOAM
% STYROFOAM CONCENTRATION
MICROCOSM MOISTURE LOSS (-) 135.49%
INITIAL $H_2O$ CONTENT 70.32%
FINAL $H_2O$ CONTENT 57.77%
EARTHWORM BODY WEIGHT LOSS (-) 107.49%
EARTHWORM SURVIVAL 87.50%
INDIVIDUAL EARTHWORM RESPIRATION 91.89%
NO PARTICLE INGESTION
INDIVIDUAL EARTHWORM LEAF CONSUMPTION 223.48%
MICROCOSM WORM LEAF CONSUMPTION 172.22%
MICROCOSM EARTHWORM RESPIRATION 94.55%
ARROWS DENOTE RELATIONSHIPS



Figure 8

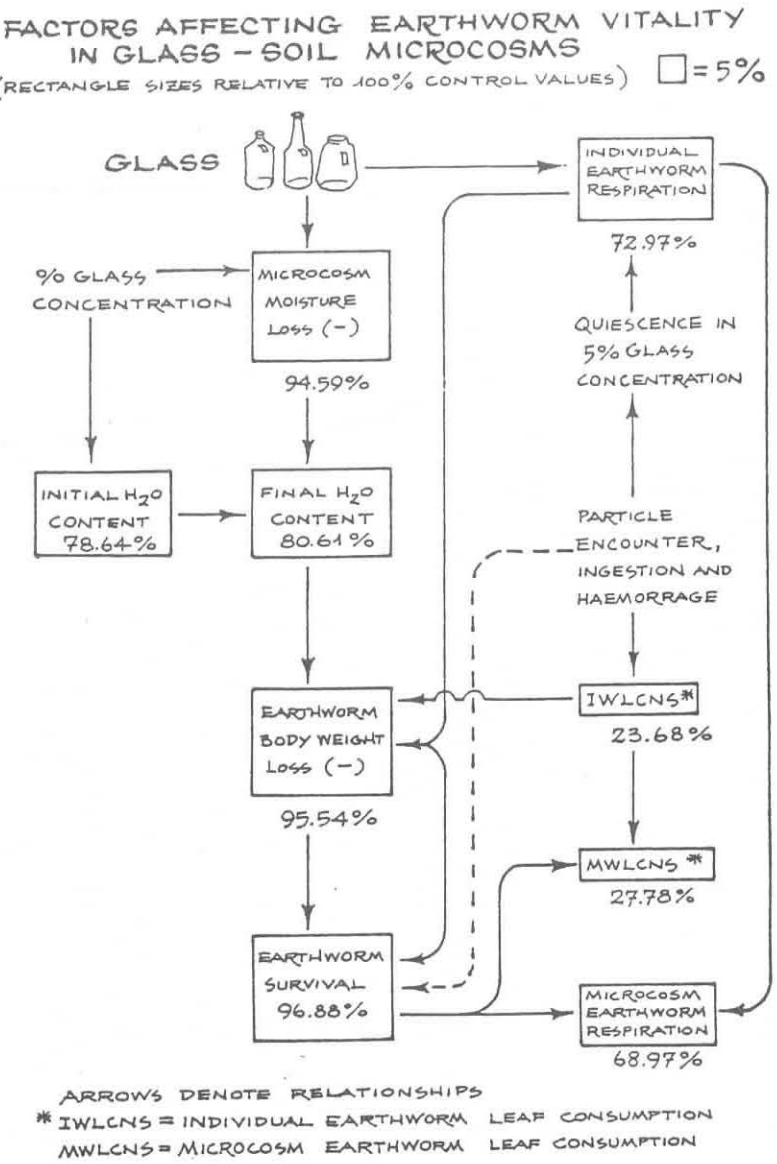

FACTORS AFFECTING EARTHWORM VITALITY
IN GLASS-SOIL MICROCOSMS
(RECTANGLE SIZES RELATIVE TO 100% CONTROL VALUES) □=5%
GLASS
% GLASS CONCENTRATION
MICROCOSM MOISTURE LOSS (-) 94.59%
INITIAL $H_2O$ CONTENT 78.64%
FINAL $H_2O$ CONTENT 80.61%
EARTHWORM BODY WEIGHT LOSS (-) 95.54%
EARTHWORM SURVIVAL 96.88%
INDIVIDUAL EARTHWORM RESPIRATION 72.97%
QUIESCENCE IN 5% GLASS CONCENTRATION
PARTICLE ENCOUNTER, INGESTION AND HAEMORRAGE
IWLCNS* 23.68%
MWLCNS* 27.78%
MICROCOSM EARTHWORM RESPIRATION 68.97%
ARROWS DENOTE RELATIONSHIPS
* IWLCNS = INDIVIDUAL EARTHWORM LEAF CONSUMPTION
MWLCNS = MICROCOSM EARTHWORM LEAF CONSUMPTION

Figure 9

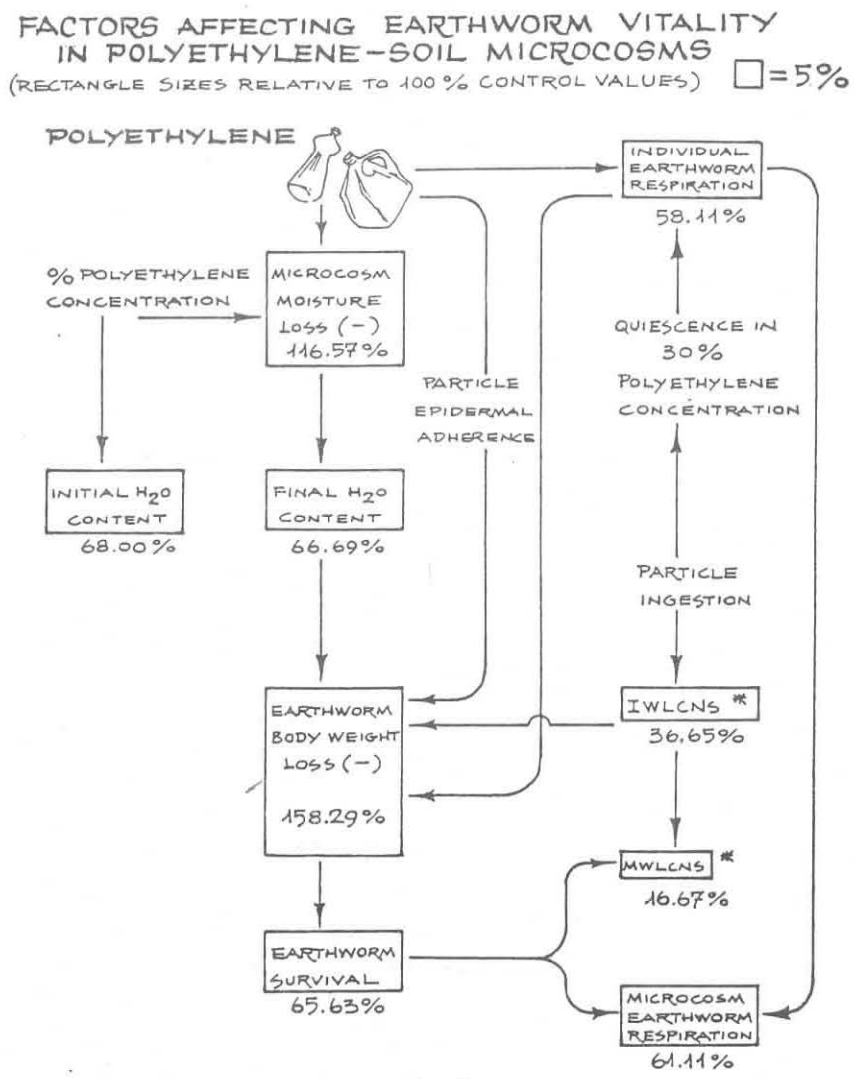

FACTORS AFFECTING EARTHWORM VITALITY
IN POLYETHYLENE-SOIL MICROCOSMS
(RECTANGLE SIZES RELATIVE TO 100 % CONTROL VALUES) □=5%
POLYETHYLENE
% POLYETHYLENE CONCENTRATION
MICROCOSM MOISTURE LOSS (-) 116.57%
INITIAL H2O CONTENT 68.00%
FINAL H2O CONTENT 66.69%
PARTICLE EPIDERMAL ADHERENCE
INDIVIDUAL EARTHWORM RESPIRATION 58.11%
QUIESCENCE IN 30% POLYETHYLENE CONCENTRATION
PARTICLE INGESTION
EARTHWORM BODY WEIGHT LOSS (-) 158.29%
IWLCNS * 36.65%
MWLCNS * 16.67%
EARTHWORM SURVIVAL 65.63%
MICROCOSM EARTHWORM RESPIRATION 61.11%
ARROWS DENOTE RELATIONSHIPS
* IWLCNS = INDIVIDUAL EARTHWORM LEAF CONSUMPTION
MWLCNS = MICROCOSM EARTHWORM LEAF CONSUMPTION



Figure 10: Leaf consumption vs. respiration of Lumbricus terrestris.

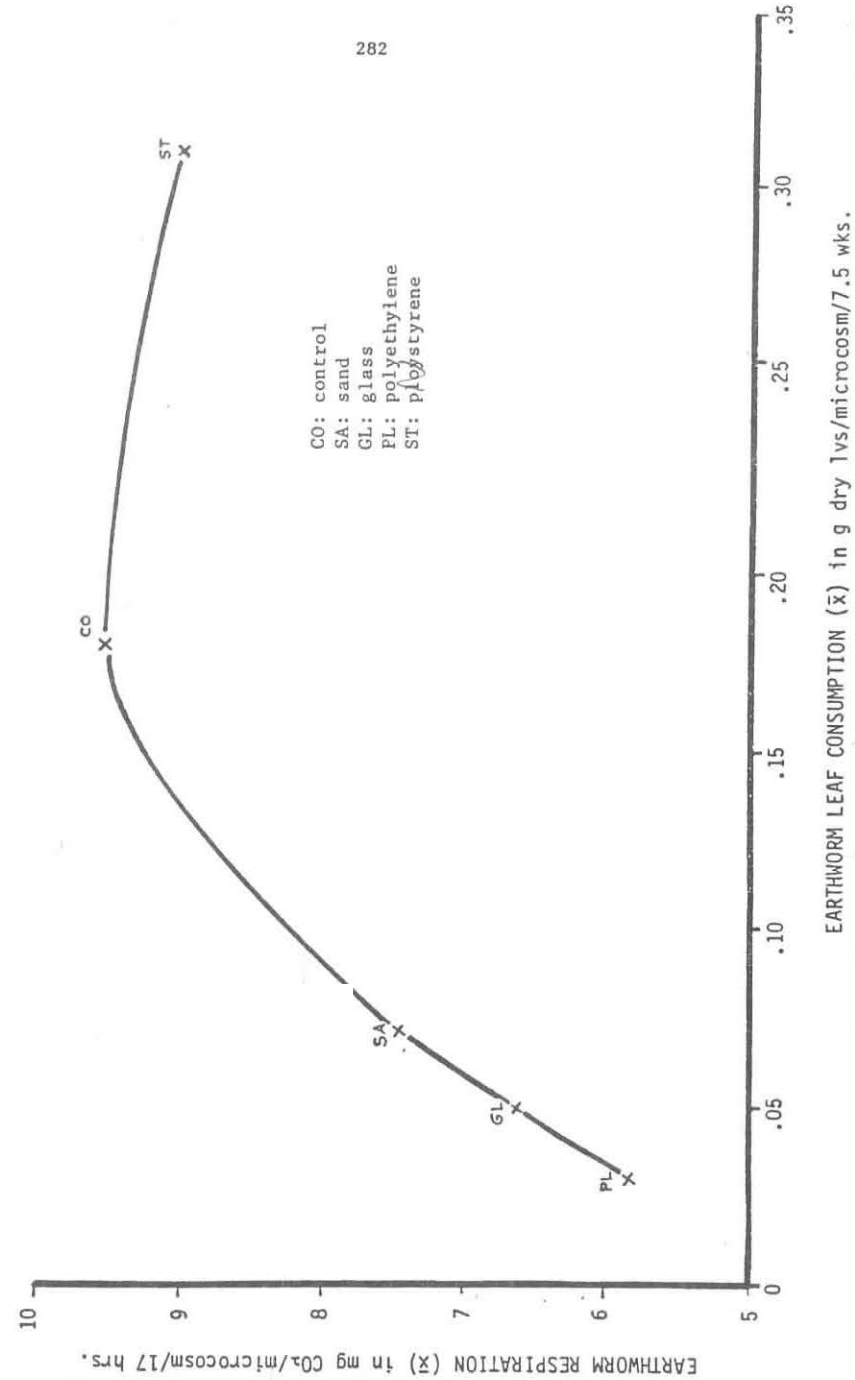
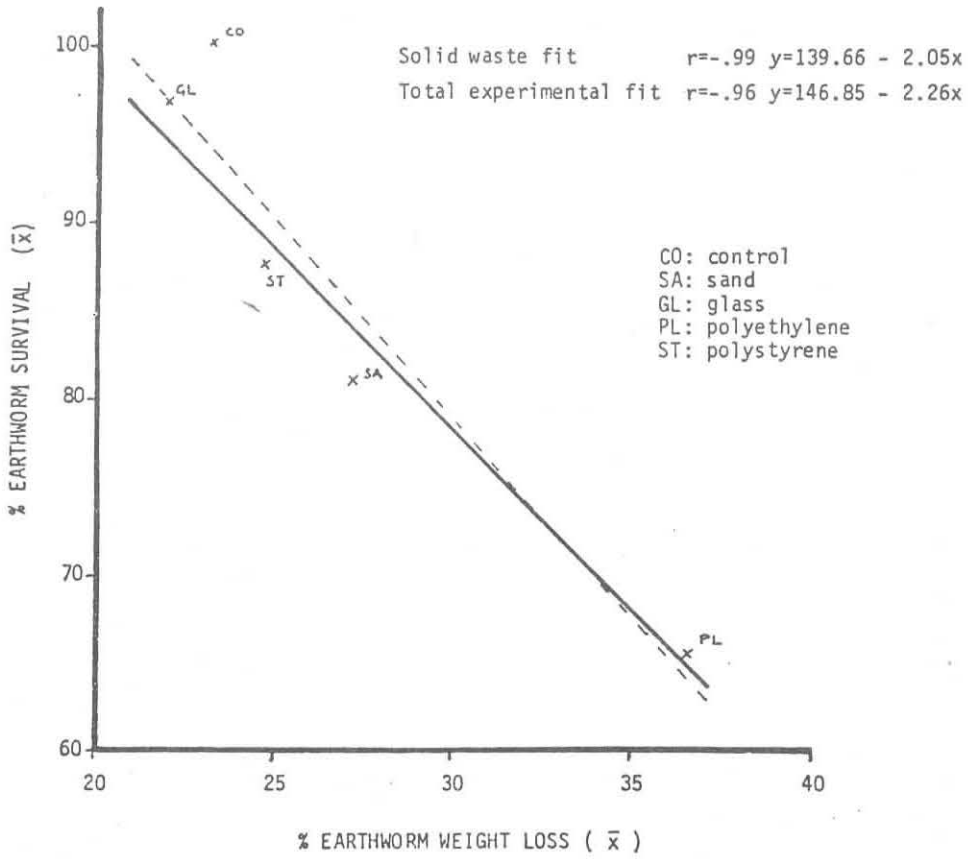


Figure 11: Relationship of body weight loss to survival of Lumbricus terrestris.





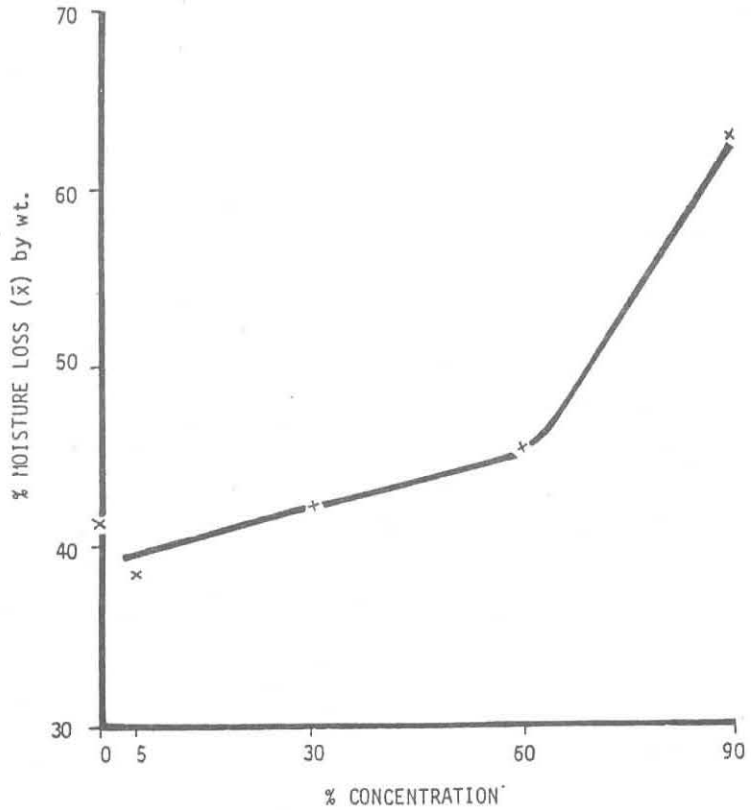


Figure 12: Moisture loss of microcosms vs. material concentrations.